JC20 Rec'd PCT/PTO 13 AUG 2001

FORM PTO-1390 (REV. 5-93) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE **TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371**	ATTORNEY'S DOCKET NUMBER **2345/163** U.S. APPLICATION NO. (If known, see 37 CFR 1.5) 09/913375

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED:
PCT/EP00/00420	**20 January 2000 (20.01.00)**	**12 February 1999 (12.02.99)**

TITLE
METHOD FOR MONITORING THE TRANSMISSION QUALITY OF AN OPTICAL TRANSMISSION SYSTEM, IN PARTICULAR OF AN OPTICAL WAVELENGTH-DIVISION MULTIPLEX NETWORK

APPLICANT(S) FOR DO/EO/US
HANIK, Norbert and SCHMID, Herbert

Applicant(s) herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) immediately rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☒ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US)
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). (UNSIGNED)
10. ☒ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A **FIRST** preliminary amendment.
    ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
14. ☒ A substitute specification and a marked up version of the substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☒ Other items or information: International Search Report; International Preliminary Examination Report; and Form PCT/RO/101.

Express Mail No.: EL244503829US

518 Rec'd PCT/PTO 13 AUG 2001

U.S. APPLICATION NO. (if known, see 37 C.F.R. 1.5) 09/913375	INTERNATIONAL APPLICATION NO. PCT/EP00/00420	ATTORNEY'S DOCKET NUMBER 2345/163

	CALCULATIONS	PTO USE ONLY
17. ☒ The following fees are submitted: **Basic National Fee (37 CFR 1.492(a)(1)-(5)):** Search Report has been prepared by the EPO or JPO .... $860.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) ...... $690.00 No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) .... $710.00 Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO .... $1,000.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) $100.00		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 860	
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$	

Claims	Number Filed	Number Extra	Rate		
Total Claims	9 - 20 =	0	X $18.00	$0	
Independent Claims	1 - 3 =	0	X $80.00	$0	
Multiple dependent claim(s) (if applicable)			+ $270.00	$	
TOTAL OF ABOVE CALCULATIONS =				$860	
Reduction by 1/2 for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (Note 37 CFR 1.9, 1.27, 1.28).				$	
SUBTOTAL =				$860	
Processing fee of $130.00 for furnishing the English translation later the ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$	
TOTAL NATIONAL FEE =				$860	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). $40.00 per property +				$	
TOTAL FEES ENCLOSED =				$860	
				Amount to be refunded	$
				charged	$

a. ☐ A check in the amount of $__________ to cover the above fees is enclosed.

b. ☒ Please charge my Deposit Account No. 11-0600 in the amount of $860.00 to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 11-0600. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

Richard Mayer
SIGNATURE

Reg. No. 33,865 Aaron C. Deditch

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NAME

8/13/2001
DATE

CUSTOMER NO. 26646

518 Rec'd PCT/PTO 13 AUG 2001

FORM PTO-1390 (REV. 5-93)	U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTORNEY'S DOCKET NUMBER **2345/163**
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		U.S. APPLICATION NO. (If known, see 37 CFR 1.5) 09/913375

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED:
PCT/EP00/00420	**20 January 2000 (20.01.00)**	**12 February 1999 (12.02.99)**

TITLE
METHOD FOR MONITORING THE TRANSMISSION QUALITY OF AN OPTICAL TRANSMISSION SYSTEM, IN PARTICULAR OF AN OPTICAL WAVELENGTH-DIVISION MULTIPLEX NETWORK

APPLICANT(S) FOR DO/EO/US
HANIK, Norbert and SCHMID, Herbert

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[2345/163]

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s)	:	Norbert HANIK et al.
Serial No.	:	To Be Assigned
Filed	:	Herewith
For	:	METHOD FOR MONITORING THE TRANSMISSION QUALITY OF AN OPTICAL TRANSMISSION SYSTEM, IN PARTICULAR OF AN OPTICAL WAVELENGTH-DIVISION MULTIPLEX NETWORK
Art Unit	:	To Be Assigned
Examiner	:	To Be Assigned

Assistant Commissioner
for Patents
Washington, D.C. 20231

PRELIMINARY AMENDMENT AND
37 C.F.R. § 1.125 SUBSTITUTE SPECIFICATION STATEMENT

SIR:

Please amend without prejudice the above-identified application before examination, as set forth below.

IN THE TITLE:

Please replace the title with the following:
--METHOD FOR MONITORING THE TRANSMISSION QUALITY OF AN OPTICAL TRANSMISSION SYSTEM, IN PARTICULAR OF AN OPTICAL WAVELENGTH-DIVISION MULTIPLEX NETWORK--.

IN THE SPECIFICATION AND ABSTRACT:

In accordance with 37 C.F.R. § 1.121(b)(3), a Substitute Specification (including the Abstract, but without claims) accompanies this response. It is respectfully requested that the Substitute Specification (including Abstract) be entered to replace the Specification of record.

The Substitute Specification reflects the text of Revised Pages 1, 2, 2a and 3, associated with the International Preliminary Examination Report.

IN THE CLAIMS:

Without prejudice, please cancel original claims 1 to 9 in the original application and please cancel substitute claims 1 to 8 from Revised Pages 11 and 12, and please add new claims 10 to 18 as follows:

10. (New) A method for monitoring transmission quality of an optical signal in an optical transmission system, the method comprising:

plotting an amplitude histogram of the optical signal transmitted over the optical transmission system;

classifying the amplitude histogram of the optical signal according to at least one of bit error rates and fault causes by performing at least one of:

(i) acquiring input data from the amplitude histogram,
feeding the input data to a neural network,
generating at least one output value from the input data, and
assigning the at least one output value to at least one of the bit-error rates of the optical signal; and

ii) assigning the at least one output value to at least one of the fault causes of the optical signal.

11. (New) The method of claim 10, wherein the optical transmission system includes an optical wavelength division-multiplex network.

12. (New) The method of claim 10, further comprising:

preprocessing the amplitude histogram so that the amplitude histogram is a normalized amplitude histogram before presenting the amplitude histogram to the neural network;

selecting a predefined number of data from the normalized amplitude histogram for providing a number of selected data; and

feeding the number of selected data to at least one input neuron of the neural network, wherein the number of selected data corresponds to a number of the at least one input neuron.

13. (New) The method of claim 10, further comprising:

asynchronously sampling the optical signal following an optoelectronic conversion to obtain at least one sampled value; and

entering at least one sampled value into the amplitude histogram.

14. (New) The method of claim 13, wherein a length of a time slot used for the sampling of the optical signal is adapted to a data transmission rate so that rapid oscillations in an amplitude of the optical signal are detectable and are not averaged out.

15. (New) The method of claim 14, wherein the length of the time slot is on the order of picoseconds.

16. (New) The method of claim 10, wherein the optical signal is transmitted with a predefined fundamental wavelength over an optical channel for a wavelength-division multiplex network.

17. (New) The method of claim 10, wherein the neural network includes a multi-layer perceptron that has undergone a training using at least one training data set having a known output value and using at least one of a cascade correlation training method and a resilient backpropagation training method.

18. (New) The method of claim 10, wherein the at least one fault cause of the optical signal includes at least one of noise, cross-talk and signal distortions.

REMARKS

This Preliminary Amendment cancels without prejudice original claims 1 to 9, cancels without prejudice substitute claims 1 to 8 in the underlying PCT Application No. PCT/EP00/00420, and adds without prejudice new claims 10 to 18. The new claims conform

the claims to U.S. Patent and Trademark Office rules and do not add new matter to the application.

In accordance with 37 C.F.R. § 1.121(b)(3), the Substitute Specification (including the Abstract, but without the claims) contains no new matter. The amendments reflected in the Substitute Specification (including Abstract) are to conform the Specification and Abstract to U.S. Patent and Trademark Office rules or to correct informalities. As required by 37 C.F.R. § 1.121(b)(3)(iii) and § 1.125(b)(2), a Marked Up Version Of The Substitute Specification comparing the Specification of record and the Substitute Specification also accompanies this Preliminary Amendment. In the Marked Up Version, shading indicates added text and bracketing indicates deleted text. Approval and entry of the Substitute Specification (including Abstract) is respectfully requested. The Substitute Specification reflects the text of Revised Pages 1, 2, 2a and 3 associated with the International Preliminary Examination Report.

The underlying PCT Application No. PCT/EP00/00420 includes an International Search Report, dated June 2, 2000. The Search Report includes a list of documents that were uncovered in the underlying PCT Application. A copy of the Search Report accompanies this Preliminary Amendment.

The underlying PCT Application No. PCT/EP00/00420 also includes an International Preliminary Examination Report, dated May 9, 2001, and an annex (including substitute claims 1 to 8 and the specification text and claims of Revised Pages 1, 2, 2a, 3, 11 and 12, associated with the International Preliminary Examination Report). An English translation of the International Preliminary Examination Report and of the annex accompanies this Preliminary Amendment.

Applicants assert that the subject matter of the present application is new, non-obvious, and useful. Prompt consideration and allowance of the application are respectfully requested.

Respectfully Submitted,

KENYON & KENYON

Dated: 8/13/2001

By: Richard L. Mayer

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09/913375
518 Rec'd PCT/PTO 13 AUG 2001
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[2345/163]

METHOD FOR MONITORING THE TRANSMISSION QUALITY OF AN OPTICAL TRANSMISSION SYSTEM, IN PARTICULAR OF AN OPTICAL WAVELENGTH-DIVISION MULTIPLEX NETWORK

Field of the Invention

The present invention is directed to a method for monitoring the transmission quality of an optical transmission (communication) system, in particular of an optical wavelength-division multiplex network.

Background of the Invention

In every optical transmission system, particularly, however, in optical wavelength division-multiplex systems (WDM systems), the problem arises of having to monitor the transmission quality, in order to guarantee a certain (quality of service - QoS) and to be able to detect slow system degradations. Transparent, optical wavelength division-multiplex systems are being increasingly used since they significantly increase the capacity and flexibility of today's information and telecommunications networks. In this context, not only is an optical signal of a single wavelength transmitted via an optical fiber, but, by employing a plurality of wavelengths, a plurality of mutually independent optical channels is made available. Optical wavelength division-multiplex networks are transparent, analog transmission systems, which are generally used for transmitting digital useful signals and, thus, render possible the implementation of many different telecommunications services. One of the important advantages of transparency is that the data rates and the format for each optical channel of a wavelength division-multiplex system can be selected independently of one another. This additionally acquired flexibility accommodates the demands of customers and

09/913375
518 Rec'd PCT/PTO 13 AUG 2001

PCT/EP00/00420

Translation of German revised pages 2, 2a, 3, 11, 12

poses a serious problem in transparent networks, precisely because of the undefined data format.

An important parameter for assessing the quality of service of a digital signal in the transmission over an optical network, is the bit error rate (BER). Usually, to estimate the BER of the transmitted useful signal, specific overhead bytes of the selected transmission format (e.g., SDH, ATM, etc.) are analyzed. However, this method cannot be used in transparent optical systems, where the data format is a priori not defined. Moreover, the evaluation of the BER does not permit any conclusions to be drawn with respect to the cause of a possibly occurring signal degradation. If, on the other hand, merely the eye diagram of the received data signal is evaluated in order to assess the signal quality, then this method requires the bit timing of the signal to be evaluated as well. Electronically acquiring the bit timing is only possible, with a justifiable outlay (reasonable expenditure), for fixed data rates known to the system to be evaluated. This ancillary condition unacceptably restricts the transparency of optical transport networks (WDM networks).

From the publication, "Application of Amplitude Histograms for Quality of Service Measurements of Optical Channels and Fault Identification" by K. Mueller et al., in ECOC 98, September 20-24, 1998, pp. 707-708, Madrid, Spain, a method has become known for characterizing optical transmission channels, which provides for evaluating amplitude histograms. These are acquired in that the optical signal is detected by a photodiode, which, in turn, emits an electric signal that is sampled asynchronously. The amplitude histograms enable conclusions to be drawn with respect, for example, to the extent and the cause of slow degradations in the transmission

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the input data, generates output values, and the output values are assigned to estimates of the bit-error rate of the signal, and/or

[REVISED PAGE 2A]

- the output values are assigned to causes of fault (interference) of the signal, such as noise, cross-talk, and signal distortions.

Advantageous further refinements of the present invention are characterized in the dependent claims.

The method according to the present invention makes it possible to assess the quality of service (characterized by the bit error rate BER) of a transparent, digital useful signal, by acquiring analog values independently of the data rate to be analyzed and the cause (e.g., noise, dispersion, crosstalk...) and level (magnitude) of the system degradation. In contrast to known methods which determine the bit error rates at the digital level and, thus, assess an analog transmission system on the basis of digital parameters, the method according to the present invention employs an essentially direct assessment criterion, namely the amplitude distribution of the analog optical transmission signal. From this amplitude distribution, information is obtained on the state of the communication system. This is accomplished using a neural network, in that the information is assigned to specific digital parameters, namely to specific values of the BER. In addition, by evaluating an amplitude histogram, conclusions can be drawn with respect to the type of fault that results in a specific BER. This information is essentially found in the amplitude distribution and is lost when an analysis is made at the digital level. Therefore, the method according to the present invention also permits inferences to be made with respect to the cause of the fault or degradation and, thus, for one to selectively intervene in the communication system in order to eliminate these influences. Furthermore, the need for knowledge of the transmission rate or of the transmission format is advantageously eliminated. **[REVISED PAGE 3]**

quality.

From Patents of Japan, vol. 1998, no. 14, JP 10 23 92 14 A, published on September 11, 1998, a method is known for calculating the loss in the transition region between two optical waveguides (connection loss) for an operational wavelength. The calculation is carried out using a neural network, which undergoes a training until the

[REVISED PAGE 2]

difference between the output signal from the neural network and a training signal exceeds a specific value.

From the publication, "Optical Signal Quality Monitoring Method Based on Optical Sampling" by I. Shake et al., in Electronics Letters, vol. 34, no. 22, October 29, 1998, pp. 2152-2154, a method is known for monitoring the average Q-factor of an optical signal in an optical transmission system, amplitude histograms of optical signals being measured. From this, information is derived about the signal-to-noise ratio of a digital signal.

The publication, "Training Techniques for Neural Network Applications in ATM" by Atsushi Hiratsu, in IEEE Communications Magazine, IEEE Service Center, Piscataway, New York, U.S., no. 10, vol. 33, October 1, 1995, pp. 58, 63-67, ISSN 0163-6804, discusses the training of neural networks.

Technical Objective

The object of the present invention is, therefore, to provide a method for monitoring the transmission quality of an optical transmission system, which is suited, in particular, for controlling a transparent transmission system, for example a WDM network, in which the data rate and the transmission format are defined flexibly and, not, fixed a priori.

Summary of the Invention

This objective is achieved by a method for monitoring the transmission quality of an optical transmission system, in which an amplitude histogram of an optical signal transmitted over the transmission system (transmission signal) is plotted, and is classified according to bit error rates and/or causes of faults, characterized in that

- from the amplitude histogram, input data are acquired (extracted), which are fed to a neural network, which, from

The essential principle underlying the present invention is to assess the BER with the aid of learning, neural networks and analog signal values in the form of amplitude histograms as input or measured data, and to pinpoint the cause of a signal degradation. In this context, the method functions (procedure works) as follows: The transmission signal is recorded (picked up) using an optical detector, preferably a photodiode having a high bandwidth. The detector's electric output signal is sampled asynchronously. For this, there is no need for any timing recovery. Important to the sampling is an arbitrarily selected time slot and the collection of a large number of sampled values which all contain relevant statistical properties of the signal. It is also important that the time slots of the sampling units be short enough to also permit rapid, oscillator-type disturbances, such as those caused by inband crosstalk, to be detected. The amplitude histogram can be recorded using an oscilloscope, for example, which queries the output signal from the detector on the basis of a timing raster (in a timing pattern).

The data of the amplitude histogram are normalized to make to them independent of absolute amplitude values and of the selected scaling of the histogram. The recorded amplitude histogram data are subsequently preprocessed in appropriate fashion to enable them to be presented to the neural network. For this purpose, a specific number of y-values, determined at set (defined) x-values of the histogram diagram, are taken from the amplitude histogram (see Figure 2). The extracted values are subsequently uniformly raised such that the highest value is < 1. At this point, the values are presented to the neurons of the input layer.

The number of values corresponds to the number of input neurons of the neural network. The neural network propagates the applied values through the network, assigns the input data to a corresponding bit-error rate class, and, as a further output value, flags the type of fault. The functioning and

method of operation of neural networks are adequately described in the technical literature. In practice, they are implemented on a data-processing device using a computer program.

In order for the neural networks to solve the tasks assigned to them, it is necessary to first train them. For this purpose, various training models are selected and collected in a training model file (data set). The training models are, for example, calculated or measured and preprocessed amplitude histograms, which correspond to various known bit-error rate classes and types of faults.

Neural networks are learning, connectionist systems. They are generally composed of a layer of neurons, which make up the input layer (input neurons), of one or a plurality of hidden layers (hidden neurons), and of a layer of neurons which make up the output layer. Each neuron has a specific transfer function. Among the neurons of the various layers, connections exist having different weightings (positive, zero, or negative). The input value of a neuron is derived from the totality of the weighted output values from the neurons of the preceding layer.

In the training, the individual weights of the connections among the neurons are adjusted to allow the correct output to appear for the input. The functioning and method of operation of the various training algorithms for neural networks are known in principle. Prior to training or using the neural network, one selects the neural network topology and the training method to be employed. What has proven to be particularly suited as a neural network is a multi-layer perceptron that has undergone a training using a number of training data sets, with the application of the cascade correlation (CC) or resilient backpropagation (RProp) training methods.

The advantage of the method is that there is no need to develop any mathematical algorithms to provide information about the type of fault that is occurring and the degree of signal degradation. All signals can be analyzed without knowledge of the transfer format and/or the timing; for that reason, the transparency of optical transmission systems, such as WDM networks, is optimally supported and not restricted. Since neural networks are massively parallel structures, a result is available much more rapidly than a result obtained from a mathematical algorithm. A further benefit of the method is that even when assessing unknown, unanticipated input models, meaningful output values are derived.

Brief Description of the Drawing

Figure 1 a block diagram of a method according to the present convention;

Figure 2 an amplitude histogram of an optical transmission signal;

Figure 3 the topology of a neural network in the form of a multi-layer perceptron.

Figure 1 illustrates a block diagram of a method according to the present invention. From an optical WDM signal, which can be composed of a multiplicity of wavelength components, an optical channel is selected with the aid of an optical filter. Consequently, only light in a specific wavelength range transmitted by the filter falls on (strikes) an optoelectronic transducer device. The transducer device is a photodetector, preferably a photodiode having a high bandwidth, so that even rapid changes in the optical signal can be detected. For example, a photodiode having a 20 Ghz receiving bandwidth is used. The transducer device emits an electric output signal, whose time characteristic essentially corresponds to that of the optical transmission signal of the detected wavelength. This electronic output signal is sampled asynchronously, the signal height being measured at arbitrary points in time (instants), in each case, integrated over a time slot of a

predefined length. To prevent signal fluctuations from being averaged out within the time slot and, thus, to also be able to record rapid signal fluctuations, time slots on the order of picoseconds are used for data rates in the range of Gbit/s. To obtain the complete statistics of the transmission signal, a multiplicity of such sampled values are collected, preferably a few thousand up to a few hundred thousand per histogram. From the sampled values, a histogram is set up, which indicates the relative frequency of a specific signal amplitude and, as the case may be, of a specific sampled value. The data are written into a histogram data file which is analyzed by a suitably trained neural network.

Figure 2 shows three examples of histograms, which are assigned to the bit-error rate class BER = 10 -11. Figure 2 illustrates the relative frequency of a specific signal amplitude for three transmission signals. The amplitude is given in arbitrary units.

To apply the method, it is necessary to first train the neural networks being used. To this end, training data sets were used, as described in the following:

The three histograms correspond to externally modulated digital signals having a data rate of 5 GBit/s and a non-return-to-zero (NRZ) data format. The digital data were produced using a random-number generator of the periodicity 2^{15}-1. The signal was interfered, on the one hand, by summing a delayed and attenuated signal component to simulate inband crosstalk. A noisy signal (noise) was generated by employing an attenuating element and an erbium amplifier during the signal transmission. A signal interfered by dispersion was generated by cascading standard optical fibers of variable length. Although the same bit-error rate class is assigned to each of these three types of faults in the illustrated example, Figure 2 reveals markedly different amplitude histograms, which can be used, in accordance with the present

invention, to infer the cause of the fault through model allocation. The differences in the characteristic curve of the amplitude histogram in response to different causes of faults are acquired (gathered) in accordance with the present invention by a neural network and assigned to a specific bit-error rate class and to one or a plurality of causes of faults. In this context, it is also possible to identify mixed causes of faults.

To automate analyzing the histograms and to assign them to bit-error rate classes, neural networks are used. An example of such a neural network, which proves to be suited for implementing the method, is depicted in Figure 3. Figure 3 shows the topology of a "multi-layer perceptron" neural network. It has an input register of 50 input neurons which are used for inputting 50 values from the histogram (input vector). These input values are mapped by the neural network onto a number of output values, the output vector. The input-output relation is not known, but must be taught to the neural network. It can be modified by adjusting the individual weights of the connections among the neurons of the individual layers, in a training procedure. In this case, the neural network was trained using the "backpropagation" algorithm. It is described, for example, in A. Hiramatsu: Training Techniques for Neural Network Applications in ATM, IEEE Communication Magazine, Oct. 1995, pp. 58-67.

To assign measured histograms to bit-error rate classes, 370 histograms representing transmission signals having bit error rates of 10^{-12} through 10^{-5} were plotted on a trial basis. The signal degradation was caused by noise, crosstalk, or dispersion. In a data preprocessing, 50 values from each histogram were compiled in an input data set for the neural network and used as an input for the neural network. A portion of the input data sets were used as a training input model, the rest as a test input model, in order to validate the method of the present invention. The neural network was

trained using the training models, in which case one of the training algorithms "resilient backpropagation" (Rprop) or "cascade correlation" (CC) was used. Following the training phase, the test models were applied to determine whether the neural network assigned the correct, previously experimentally determined bit error rates to the test histograms.

Each output neuron of the neural network in Figure 3 represents a bit-error rate class of 10^{-5} through 10^{-12}. The amplitude of the signal at the particular output neuron indicates to which BER class(es) the input model is to be assigned. In the above example, the plotted amplitude histograms were able to be assigned with very high level of reliability to the previously determined BER class.

In a further refinement of the method, the neural network is preferably trained such that, besides the BER class, the type of fault can also be inferred from the output vector, i.e., from the entries of the output neurons. For this, it is necessary to provide the right number of output neurons, to ensure that the output vector represents the relevant BER classes, as well as the relevant types of faults. Therefore, in the above example including eight BER classes and three types of faults, it is necessary to provide ten output neurons and to train the neural network accordingly.

Industrial Applicability:

The present invention advantageously has industrial applicability for monitoring the transmission quality of an analog, optical transmission system, in particular of a WDM network. Besides making it possible to classify the transmission quality in accordance with specific bit-error rate classes, the method of the present invention also makes it possible to detect (search out) causes of degradation. This enables a selective counter-control on the part of the telecommunications carrier to prevent further system degradation.

What is claimed is:

1. A method for monitoring the transmission quality of an optical transmission system, in which an amplitude histogram of an optical signal transmitted over the transmission system (transmission signal) is plotted, and is classified according to bit error rates and/or causes of faults, wherein

- from the amplitude histogram, input data are acquired, which are fed to a neural network, which, from the input data, generates output values, and the output values are assigned to estimates of the bit-error rate of the signal, and/or
- the output values are assigned to causes of fault of the signal, such as noise, cross-talk, and signal distortions.

2. The method as recited in Claim 1, wherein the transmission system is an optical wavelength division-multiplex network.

3. The method as recited in Claim 1 or 2, wherein prior to being presented to the neural network, the amplitude histogram is preprocessed in that it is normalized, and a predefined number of data is selected therefrom, and is fed to the input neurons of the neural network, the number of selected data corresponding to the number of input neurons.

4. The method as recited in one of the Claims 1 through 3, wherein, following optoelectronic conversion, the transmission signal is sampled asynchronously, and the sampled values are entered into the amplitude histogram.

5. The method as recited in Claim 4, wherein the length of the time slot used for sampling the optical signal is adapted to the data transmission rate in such a way that even rapid oscillations in the amplitude of the transmission signal can be detected and are not averaged out.

[REVISED PAGE 11]

6. The method as recited in Claim 5, wherein the length of the time slot is on the order of picoseconds.

7. The method as recited in one of the Claims 1 through 6, wherein in the case of a wavelength-division multiplex network, the transmission signal is the signal transmitted with a predefined fundamental wavelength over an optical channel.

8. The method as recited in one of Claims 1 through 7, wherein the neural network is a multi-layer perceptron that has undergone a training using a number of training data sets, whose output value is known, with the application of the cascade correlation, CC, or resilient backpropagation, RProp training methods.

[REVISED PAGE 12]

09/913375

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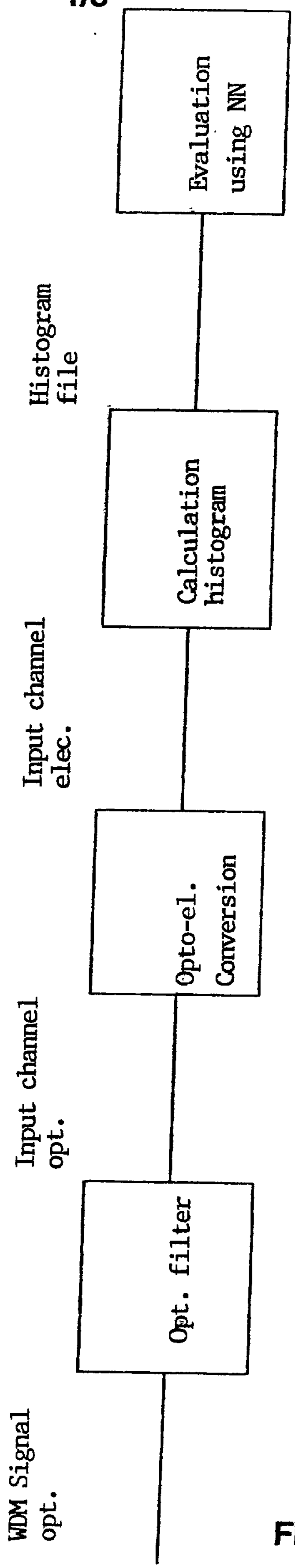

Fig. 1

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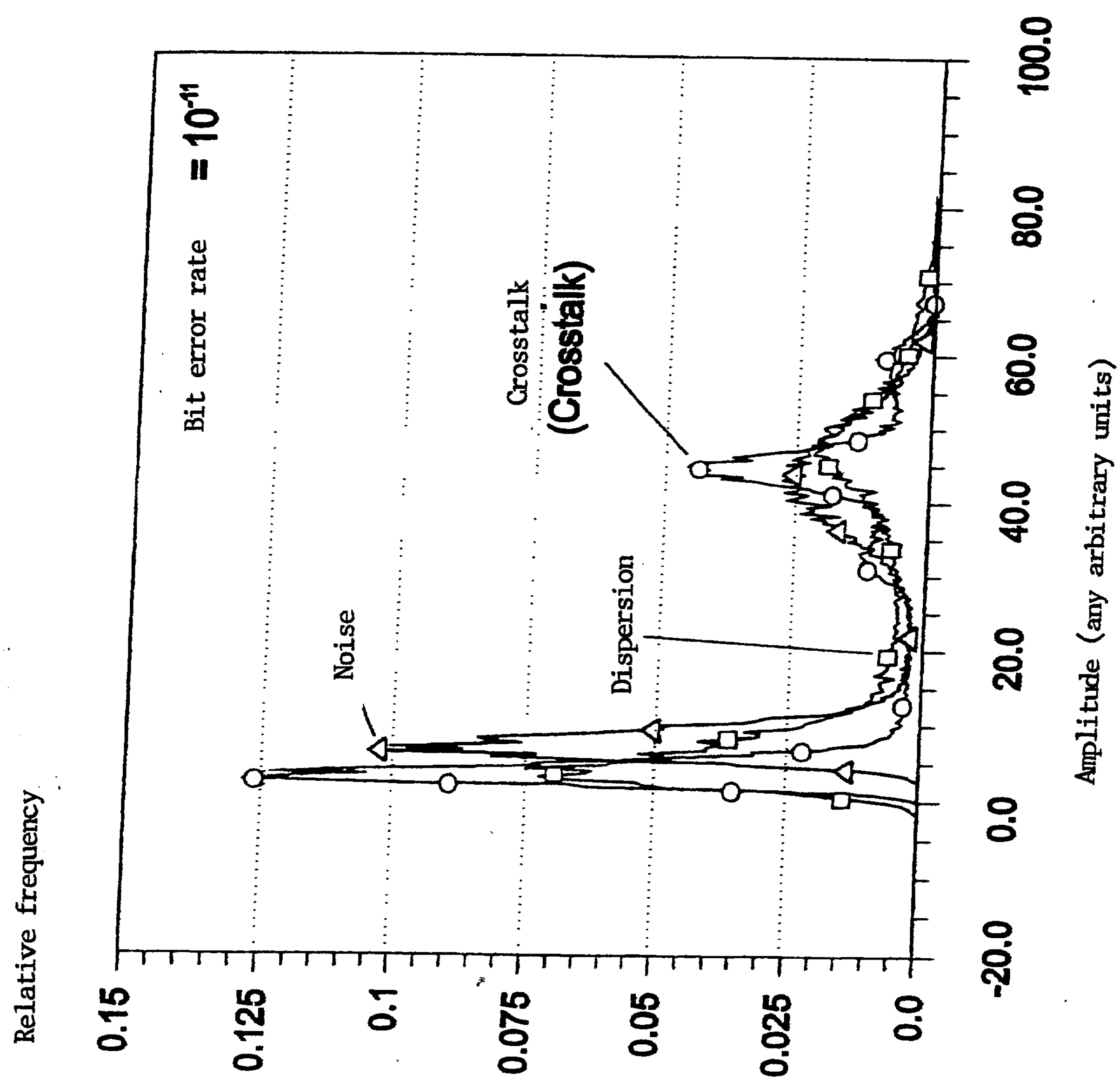

Fig. 2

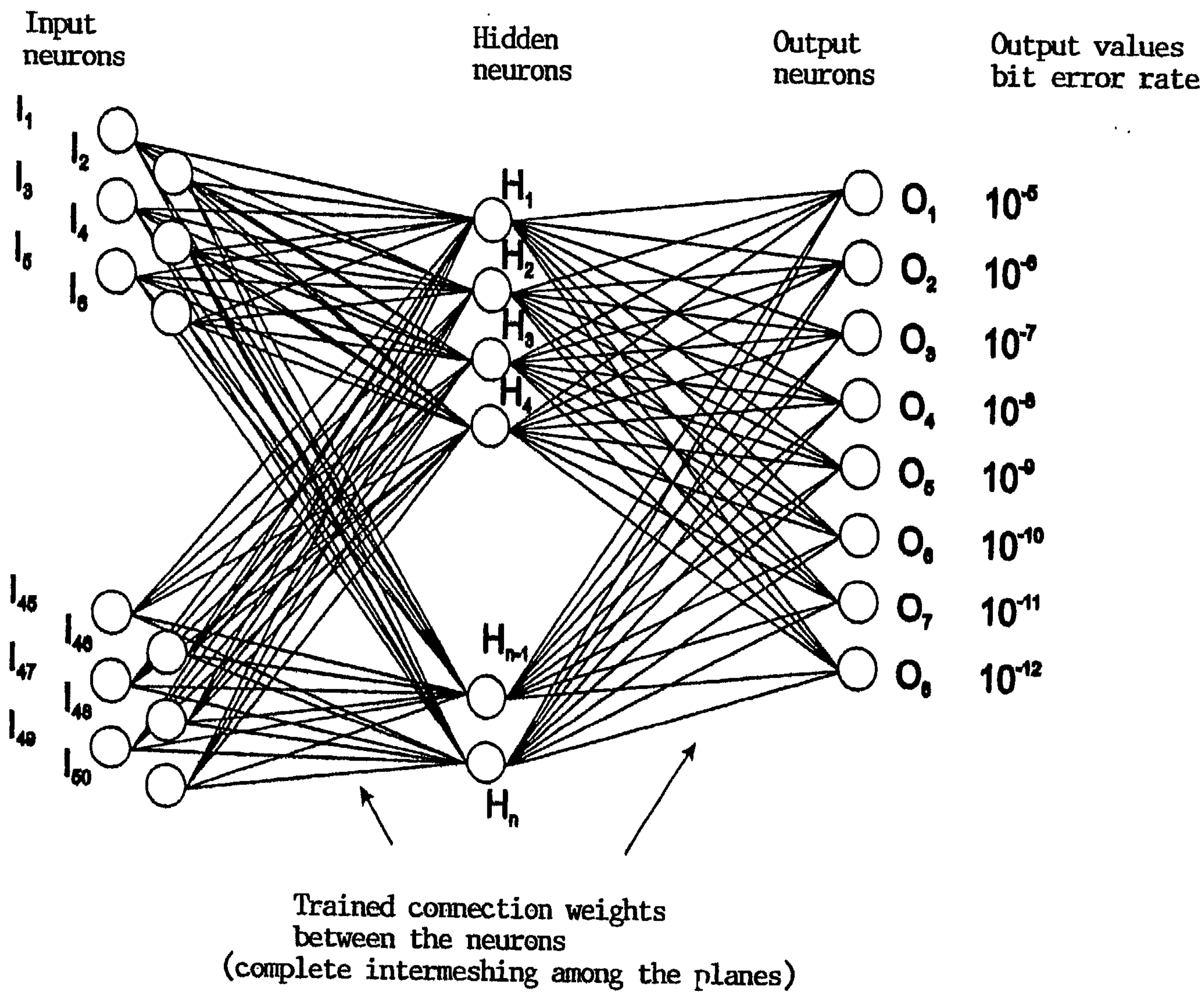

Fig. 3

Multi-layer perceptron

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METHOD FOR MONITORING THE TRANSMISSION QUALITY OF AN OPTICAL TRANSMISSION SYSTEM, IN PARTICULAR OF AN OPTICAL WAVELENGTH-DIVISION MULTIPLEX NETWORK

FIELD OF THE INVENTION

The present invention is directed to a method for monitoring the transmission quality of an optical transmission communications system, in particular of an optical wavelength-division multiplex network.

BACKGROUND INFORMATION

In optical transmission systems including, for example, in optical wavelength division-multiplex systems (WDM systems), the problem may arise of having to monitor the transmission quality, in order to guarantee a certain (quality of service - QoS) and to be able to detect slow system degradations. Transparent, optical wavelength division-multiplex systems may be increasingly used, perhaps because they are believed to significantly increase the capacity and flexibility of today's information and telecommunications networks. Not only is an optical signal of a single wavelength transmitted via an optical fiber, but, by employing a plurality of wavelengths, a plurality of mutually independent optical channels may be made available.

Optical wavelength division-multiplex networks are transparent, analog transmission systems, which may be used for transmitting digital useful signals, and for implementing different telecommunications services. The transparency involves selecting the data rates and the format for each optical channel of a wavelength division-multiplex system independently of one another. This additionally acquired flexibility may be used to accommodate the demands of customers and to facilitate the integration of new services.

SUBSTITUTE SPECIFICATION

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It is believed that the undefined data format may pose a serious problem in transparent networks.

The bit error rate (BER) may be considered in assessing the quality of service of a digital signal in the transmission over an optical network. It is believed that to estimate the BER of the transmitted useful signal, specific overhead bytes of the selected transmission format (e.g., SDH, ATM, etc.) are analyzed. It is believed that this method cannot be used in transparent optical systems, where the data format is "a priori" not defined. Moreover, the evaluation of the BER does not appear to permit any conclusions to be drawn with respect to the cause of a possibly occurring signal degradation. If merely the eye diagram of the received data signal is evaluated in order to assess the signal quality, then it is believed that this method requires the bit timing of the signal to be evaluated as well. Electronically acquiring the bit timing is allowable with a justifiable outlay or reasonable expenditure for fixed data rates known to the system to be evaluated. This ancillary condition or constraint may restrict the transparency of optical transport networks (WDM networks).

The reference "Application of Amplitude Histograms for Quality of Service Measurements of Optical Channels and Fault Identification," by K. Mueller et al., ECOC 98, September 20-24, 1998, Madrid, Spain, pages 707-708, discusses a method for characterizing optical transmission channels which provides for evaluating amplitude histograms. It is believed that these are acquired in that the optical signal is detected by a photodiode, which, in turn, emits an electric signal that is sampled asynchronously. The amplitude histograms may enable conclusions to be drawn with respect, for example, to the extent and the cause of slow degradations in the transmission quality.

The reference Patents of Japan, vol. 1998, no. 14, JP 10 23 92 14 A, September 11, 1998, discusses a method for calculating the loss in the transition region between two optical waveguides (connection loss) for an operational wavelength. It is believed that the calculation may be carried out using a neural network, which undergoes a training until the difference between the output signal from the neural network and a training signal exceeds a specific value.

The reference "Optical Signal Quality Monitoring Method Based on Optical Sampling," I. Shake et al., Electronics Letters, vol. 34, no. 22, October 29, 1998, pages 2152-2154, discusses a method for monitoring the average Q-factor of an optical signal in an optical transmission system, amplitude histograms of optical signals being measured. From this, it is believed that information is derived about the signal-to-noise ratio of a digital signal.

The reference "Training Techniques for Neural Network Applications in ATM," Atsushi Hiratsu, IEEE Communications Magazine, IEEE Service Center, Piscataway, New York, U.S.A., no. 10, vol. 33, October 1, 1995, pages 58, 63-67, discusses the training of neural networks.

SUMMARY OF THE INVENTION

An exemplary method of the present invention is directed to providing a method for monitoring the transmission quality of an optical transmission system, which may be suited, for example, for controlling a transparent transmission system, for example, a WDM network, in which the data rate and the transmission format are defined flexibly and not fixed "a priori".

Another exemplary method of the present invention is directed to providing a method for monitoring the transmission quality of an optical transmission system, in which an amplitude

histogram of an optical signal transmitted over the transmission system (transmission signal) may be plotted, and may be classified according to bit error rates and/or causes of faults, including:

- from the amplitude histogram, input data are acquired (or extracted), which are fed to a neural network, which, from the input data, generates output values, and the output values are assigned to estimates of the bit-error rate of the signal, and/or
- the output values are assigned to causes of fault (or interference) of the signal, such as noise, cross-talk, and signal distortions.

Another exemplary embodiment and/or exemplary method of the present invention is directed to assessing the quality of service (characterized by the bit error rate BER) of a transparent, digital useful signal, by acquiring analog values independently of the data rate to be analyzed and the cause (e.g., noise, dispersion, crosstalk...) and level (or magnitude) of the system degradation. In contrast to methods which may determine the bit error rates at the digital level and, thus, may assess an analog transmission system on the basis of digital parameters, an exemplary method of the present invention is directed to providing a method which employs an essentially direct assessment criterion, namely the amplitude distribution of the analog optical transmission signal.

From this amplitude distribution, information may be obtained on the state of the communication system. This may be accomplished using a neural network, in that the information may be assigned to specific digital parameters, namely to specific values of the BER. In addition, by evaluating an amplitude histogram, conclusions may be drawn with respect to the type of fault that results in a specific BER. This information may be essentially found in the amplitude

distribution and may be lost when an analysis is made at the digital level. Another exemplary embodiment and/or exemplary method of the present invention is directed to permitting inferences to be made with respect to the cause of the fault or degradation and, thus, for one to selectively intervene in the communication system in order to eliminate these influences. Furthermore, the need for knowledge of the transmission rate or of the transmission format may be eliminated.

Another exemplary embodiment and/or exemplary method of the present invention is directed to assessing the BER with the aid of learning, neural networks and analog signal values in the form of amplitude histograms as input or measured data, and to pinpoint the cause of a signal degradation. In this context, the exemplary method is as follows: the transmission signal is recorded (or picked up) using an optical detector, for example, a photodiode having a high bandwidth. The detector's electric output signal is sampled asynchronously. For this, there may be no need for any timing recovery. For the sampling operation, an arbitrarily selected time slot and the collection of a large number of sampled values which all contain relevant statistical properties of the signal are found. The time slots of the sampling units should be short enough to also permit rapid, oscillator-type disturbances, such as those caused by in-band crosstalk, to be detected. The amplitude histogram may be recorded using an oscilloscope, for example, which queries the output signal from the detector on the basis of a timing raster (or in a timing pattern).

The data of the amplitude histogram are normalized to make them independent of absolute amplitude values and of the selected scaling of the histogram. The recorded amplitude histogram data may be subsequently preprocessed in appropriate fashion to enable them to be presented to the neural network. For this purpose, a specific number of y-values, determined at

set (or defined) x-values of the histogram diagram, are taken from the amplitude histogram (see Figure 2). The extracted values may subsequently be uniformly raised such that the highest value is less than 1. At this point, the values may be presented to the neurons of the input layer.

The number of values may correspond to the number of input neurons of the neural network. The neural network may propagate the applied values through the network, assign the input data to a corresponding bit-error rate class, and, as a further output value, flag the type of fault. The functioning and method of operation of neural networks may be discussed in technical literature. In practice, they may be implemented on a data-processing device using a computer program.

For the neural networks to solve the tasks assigned to them, the neural networks should first be trained. Accordingly, various training models may be selected and collected in a training model file (or data set). The training models may be, for example, calculated or measured and preprocessed amplitude histograms, which may correspond to various bit-error rate classes and types of faults.

Neural networks are learning, connectionist systems. They may be composed of a layer of neurons which make up the input layer (input neurons), of one or a plurality of hidden layers (hidden neurons), and of a layer of neurons which make up the output layer. Each neuron may have a specific transfer function. Among the neurons of the various layers, connections exist having different weightings (positive, zero, or negative). The input value of a neuron may be derived from the totality of the weighted output values from the neurons of the preceding layer.

In the training, the individual weights of the connections among the neurons may be adjusted to allow the correct output

to appear for the input in question. The functioning and method of operation of the various training algorithms for neural networks may be used. Prior to training or using the neural network, one may select the neural network topology and the training method to be employed. A multi-layer perceptron, which may have undergone a training using a number of training data sets, including with the application of the cascade correlation (CC) or resilient backpropagation (RProp) training methods, is believed to be suited as a neural network.

Thus, there should be no need to develop any mathematical algorithms to provide information about the type of fault that may be occurring and the degree of signal degradation. All signals may be analyzed without knowledge of the transfer format and/or the timing (or clock pulse). For that reason, the transparency of optical transmission systems, such as WDM networks, may be optimally supported and not restricted. Since neural networks may be massively parallel structures, the exemplary embodiments and/or exemplary methods of the present invention should provide for obtaining results much more rapidly than by using a mathematical algorithm. It is believed that another benefit of the exemplary method is that even when assessing unknown, unanticipated input models, meaningful output values may be derived.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a block diagram of an exemplary method of the present convention.

Figure 2 shows an amplitude histogram of an optical transmission signal.

Figure 3 shows a topology of a neural network in the form of a multi-layer perceptron.

DETAILED DESCRIPTION

Figure 1 shows a block diagram of an exemplary method according of the present invention. From an optical WDM signal, which may be composed of a multiplicity of wavelength components, an optical channel may be selected with the aid of an optical filter. Consequently, only light in a specific wavelength range transmitted by the filter may fall on (or strike) an optoelectronic transducer device. The transducer device may be a photodetector or a photodiode having a high bandwidth, so that even rapid changes in the optical signal can be detected. For example, a photodiode having a 20 Ghz receiving bandwidth may be used.

The transducer device may emit an electric output signal, whose time characteristic may essentially correspond to that of the optical transmission signal of the detected wavelength. This electronic output signal may be sampled asynchronously, the signal height being measured at arbitrary points in time, in each case, integrated over a time slot of a predefined length. To prevent signal fluctuations from being averaged out within the time slot and, thus, to also be able to record rapid signal fluctuations, time slots on the order of picoseconds may be used for data rates in the range of Gbit/s.

To obtain the complete statistics of the transmission signal, a multiplicity of such sampled values may be collected, for example, a few thousand up to a few hundred thousand per histogram. From the sampled values, a histogram may be set up, which indicates the relative frequency of a specific signal amplitude and, as the case may be, of a specific sampled value. The data may be written into a histogram data file which is analyzed by a suitably trained neural network.

Figure 2 shows three examples of histograms, which are assigned to the bit-error rate class BER = 10^{-11}, according to an exemplary embodiment and/or exemplary method of the present

invention. Figure 2 shows the relative frequency of a specific signal amplitude for three transmission signals. The amplitude may be given in arbitrary units.

To apply the exemplary method, the neural networks being used should first be trained. To this end, training data sets were used, as described in the following:

The three histograms correspond to externally modulated digital signals having a data rate of 5 GBit/s and a non-return-to-zero (NRZ) data format. The digital data were produced using a random-number generator of the periodicity $2^{15}-1$. The signal was interfered, on the one hand, by summing a delayed and attenuated signal component to simulate in-band crosstalk. A noisy signal (noise) was generated by employing an attenuating element and an erbium amplifier during the signal transmission. A signal interfered by dispersion was generated by cascading standard optical fibers of variable length.

Although the same bit-error rate class is assigned to each of these three types of faults in the illustrated example, Figure 2 reveals markedly different amplitude histograms, which can be used to infer the cause of the fault through model allocation. The differences in the characteristic curve of the amplitude histogram in response to different causes of faults may be acquired by a neural network and assigned to a specific bit-error rate class and to one or a plurality of causes of faults. This allows identification of mixed causes of faults.

To automate analyzing the histograms and to assign them to bit-error rate classes, neural networks may be used. An exemplary neural network is depicted in Figure 3 which shows the topology of a "multi-layer perceptron" neural network. It has an input register of 50 input neurons which may be used for inputting 50 values from the histogram (input vector).

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These input values may be mapped by the neural network onto a number of output values, the output vector. The input-output relation may not be known, but should be taught to the neural network. It may be modified by adjusting the individual weights of the connections among the neurons of the individual layers, in a training procedure. In this case, the neural network was trained using the "backpropagation" algorithm. The backpropagation algorithm is discussed in, for example, "Training Techniques for Neural Network Applications in ATM," A. Hiramatsu, IEEE Communication Magazine, October 1995, pages 58-67.

To assign measured histograms to bit-error rate classes, 370 histograms representing transmission signals having bit error rates of 10^{-12} through 10^{-5} were plotted on a trial basis. The signal degradation was caused by noise, crosstalk, or dispersion. In a data preprocessing, 50 values from each histogram were compiled in an input data set for the neural network and used as an input for the neural network. A portion of the input data sets were used as a training input model, the rest as a test input model, in order to validate the exemplary method. The neural network was trained using the training models, in which case one of the training algorithms "resilient backpropagation" (Rprop) or "cascade correlation" (CC) was used. Following the training phase, the test models were applied to determine whether the neural network assigned the correct, previously experimentally determined bit error rates to the test histograms.

Each output neuron of the neural network in Figure 3 represents a bit-error rate class of 10^{-5} through 10^{-12}. The amplitude of the signal at the particular output neuron indicates to which BER class(es) the input model is to be assigned. In the above example, the plotted amplitude histograms were able to be assigned with very high level of reliability to the previously determined BER class.

The neural network may be trained such that, besides the BER class, the type of fault may also be inferred from the output vector, i.e., from the entries of the output neurons. For this, the appropriate number of output neurons should be provided to ensure that the output vector represents the relevant BER classes, as well as the relevant types of faults. In the above example including eight BER classes and three types of faults, it follows that ten output neurons should be provided and the neural network should be trained accordingly.

The exemplary embodiment and/or exemplary method of the present invention may be used industrially for monitoring the transmission quality of an analog, optical transmission system, for example, a WDM network. Besides allowing classification of the transmission quality in accordance with specific bit-error rate classes, the exemplary embodiments and/or exemplary methods of the present invention may be used for detecting or searching out causes of degradation. This may enable a selective counter-control on the part of the telecommunications carrier to prevent further system degradation.

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ABSTRACT OF THE DISCLOSURE

A method for monitoring the transmission quality of an optical transmission system, such as, for example, an optical wavelength division-multiplex network. An amplitude histogram of an optical signal (transmission signal) transmitted over the transmission system may be plotted and classified, with the assistance of a neural network, according to bit error rates and/or causes of faults. The need for setting requirements for transmission mode, transmission format and/or transmission timing cycle of the transmission system may be eliminated. The amplitude histogram may be implemented for any signal, and causes of faults, which are not able to be determined by a conventional bit rate classification, may be allocated.

DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled **METHOD FOR MONITORING THE TRANSMISSION QUALITY OF AN OPTICAL TRANSMISSION SYSTEM, IN PARTICULAR OF AN OPTICAL WAVELENGTH-DIVISION MULTIPLEX NETWORK**, the specification of which was filed as International Application No. PCT/EP00/00420 on January 20, 2000 and filed as a U.S. application having a Serial No. 09/913,375 on August 13, 2001 for Letter Patent in the U.S.P.T.O.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application(s) for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

PRIOR FOREIGN APPLICATION(S)

Number	Country Filed	Day/Month/Year	Priority Claimed Under 35 USC 119
199 05 814.8	Fed. Rep. of Germany	February 12, 1999	Yes

Express Mail No.: EL179952326US

And I hereby appoint Richard L. Mayer (Reg. No. 22,490), Gerard A. Messina (Reg. No. 35,952) and Linda M. Shudy (Reg. No. 47,084) my attorneys with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

Please address all communications regarding this application to:

KENYON & KENYON
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CUSTOMER NO. 26646

Please direct all telephone calls to Richard L. Mayer at (212) 425-7200.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful and false statements may jeopardize the validity of the application or any patent issued thereon.

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